2009 Urban Remote Sensing Joint Event

Changing urbanity in Istanbul

Analysis of megacity developments using synergistic potentials of multi-temporal SAR and optical data

Markus Breunig [1], Hannes Taubenböck [1,2], Michael Wurm [1,2] & Achim Roth [1]

[1] German Remote Sensing Data Center (DFD),
German Aerospace Center (DLR)
82234 Wessling-Oberpfaffenhofen, Germany

[2] Julius-Maximilians University Würzburg,
Geographical Institute, Earth Observation
97074 Würzburg, Germany
hannes.taubenboeck@dlr.de

Abstract—**The current process of megacity development and urban sprawl are unique in human history. More and more so-called megacities with more than 10 million inhabitants are evolving throughout the world. The presented study is focusing on the earthquake-prone megacity Istanbul officially counting 12 million inhabitants in 2007. During the past decades, the megacity has undergone an enormous suburbanization into its outskirts. Recent urban developments, however, seem to indicate changing housing trends respectively types of urbanization in Istanbul. In our study we focus on a multi-temporal and multi-sensoral analysis using Landsat and TerraSAR-X data. By implementing an object-oriented classification approach settlement masks for 1975, 1987, 2000, and 2008 have been created. Furthermore, post-classification change detection is displaying medium and large scale urban developments of the megacity for the past decades. The results are conforming to current social studies focusing on urbanity and lifestyle: Istanbul is facing new types and factors of urban development. The study demonstrates both the synergistic usage of multi-temporal and multi-sensoral remotely sensed data. Additionally, the synergistic potential of remote sensing and applied urban studies to work out useful information for urban planners is presented.**

I. THE GEOGRAPHY OF MEGACITIES

The 20th century and especially the beginning of the 21st century are characterized by great changes having a worldwide influence on human beings. Next to globalization, climate change, and urbanization, mankind is experiencing an anthropogenic alteration taking place in urban areas all over the world. According to studies undertaken by the United Nations [1] the global population is concentrating more and more in urban agglomerations: In 1800, only 3 per cent of mankind was living in urbanized areas. Since 1950, the world has faced a dramatic growth of cities and its urban population by factor 4. Quoting Kofi Annan, the world has entered the urban millennium [2]. Today, every second human being is living in a city or agglomeration. Forecasts predict a progressive metropolization in the future decades. By 2050, two third of mankind will be ‘urban beings’.

The most spectacular and frightening performances of the current urban development can be regarded in the evolution of so-called megacities, cities with more than 10 million inhabitants. By 2015, our planet will be covered with some 20 megacities, predominantly located in developing countries. Meta-cities, counting more than 20 million inhabitants, will emerge as well. Many scientists in different disciplines e.g. applied human geography, urban remote sensing, urban planning / management, ecology, and social studies are working on the phenomenon of megacities [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. It can be observed that varying approaches are arriving at the consistent conclusion: the complex urban systems, especially of megacities with their heterogeneous, large and complex entities, require multi-disciplinary analysis techniques.

In order to develop sustainable and space-saving solutions for fast growing agglomerations like megacities, scientists as well as urban planners are in need of precise and updated information. Analysing and monitoring megacity growth are no longer manageable with one-dimensional approaches [7]. Multi-dimensional and multi-disciplinary methodologies, the usage of multiple data, expert software, and expert knowledge are necessary to understand, to describe, and to interpret the complexity of megacities - and to forecast possible future developments and scenarios.

Additionally, many megacities like Istanbul, Beijing, Mexico-City or Tokyo are so called ‘disaster risk hotspots’ since they are located in areas endangered by earthquakes, tsunamis or volcanic eruptions [16]. According to [17, 18] most megacities are facing a high vulnerability. A natural hazard would cause high risk and damage. It is obvious that these megacities have to be studied carefully and monitored permanently [19].

The study supports the idea to detect urban footprints and detect structural changes of the megacity Istanbul over time. Therefore, we use multi-temporal and multi-sensoral satellite imagery of the sensors Landsat and TerraSAR-X over three decades by taking into consideration the time steps of 1975, 1987, 2000, and 2008. We use object-oriented classification methodologies to derive individual urban footprint

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classifications for every time step. The results are compared with the conclusions of social studies focusing on Istanbul's urbanity. It seems promising that a cooperation of neighbouring disciplines like applied (human) geography, remote sensing, urban planning, and social studies is able to work out useful and essential information on the appearance and evolution of megacities over time including their latest urbanization trends.

II. THE MEGACITY ISTANBUL

The presented study is focusing on the megacity Istanbul which is located on both sides of the Bosporus and which is therefore an important connector between Europe and Asia. With 2 million inhabitants in 1960 and some 3.8 million inhabitants in 1975, Istanbul's progress towards a megacity began in the second half of the 20th century.

The former traditional mono-centric business district at the Golden Horn has been substituted by different sub-centres throughout the whole 'Istanbul Metropolitan Area' (IMA). Nowadays, so-called multi-nucleation is taking place and Istanbul's urban development is relocated from coastal to interior districts in the hinterland [20, 21]. Several dynamic progresses like intense migration to the megacity and the construction of private homes were leading to a massive suburbanization in the second half of the 20th century, especially since the 1970ies.

But one of the most severe factors can be seen in informal respectively illegal Gecekondu settling including primitive housing conditions and missing infrastructure [22]. For several decades, Istanbul has undergone an enormous urban sprawl into its outskirts and today it is showing a complex morphological urban footprint (See Figure 4). According to [23], Istanbul developed to a migrant city in which 90 per cent of urban areas have been produced within the past 50 years. Indeed, this development did not take into consideration the residual 10 per cent of the ancient city existing for more than 2000 years. Istanbul's suburbanization and urban sprawl could already be detected in various studies using remote sensing data [3, 9, 19, 24].

Since the millennium, however, the impulsive factors bringing about the urban development in Istanbul have changed. These changes shall be analysed and discussed by the results of the presented study. In 2007, Istanbul was officially counting some 12 million inhabitants. Similarly to the worldwide process of metropolization described above, Istanbul as well is experiencing a dramatic urban sprawl and enormous growth of its urban population. Forecasts predict some 25 million inhabitants in 2025 [1].

However, Istanbul, like other megacities worldwide, is facing high vulnerability. Turkey respectively the eastern part of the Mediterranean is part of a complex tectonic plate structure [25]. The megacity Istanbul is located in the seismically active 'North Anatolian Transform Fault' (NATF) which has caused amongst others the Izmir earthquake with magnitude 7.8 in 1999. During the past decades, the earthquake epicentre moved westward towards the Bosporus. Consequently, Istanbul can be titled as an earthquake-prone megacity that is said to be hit by an earthquake with a magnitude above 7.3 until 2030 [19, 26, 27]. Although institutions like the 'Earthquakes and Megacities Initiative' (EMI) and the 'Istanbul Metropolitan Municipality' (IMM) have worked out the 'Istanbul Earthquake Master Plan' (IEMP), vulnerability and damage potentials are very high in the worst case [28]. As shown above, the main part of urban area is covered with former Gecekondu settlements which do not meet the rules of sustainable and earthquake resistant housing.

III. REMOTE SENSING DATASETS

For analysing the spatiotemporal urbanization process in Istanbul four different remote sensing datasets are implemented (see Figures 1, 2, and 3). The main aim is the usage of multi-temporal and multi-sensoral remote sensing data for continuously monitoring and analysing large scale and laminar urbanization processes in the megacity over time.

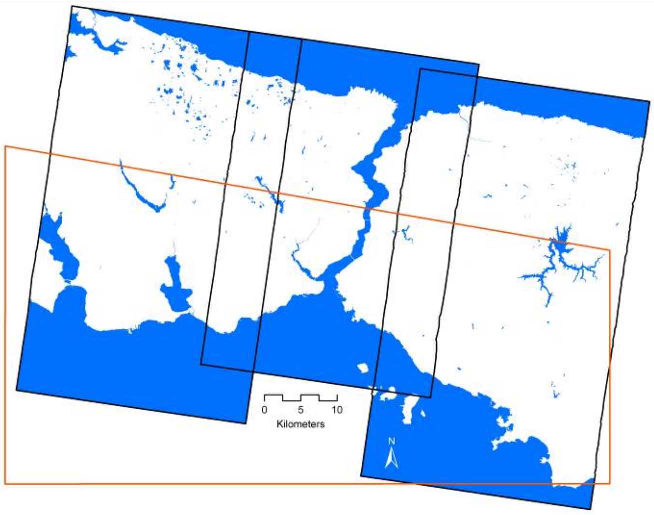

Figure 1. Spatial overview of the used remote sensing datasets in Istanbul (Orange: Landsat MSS, TM, ETM / Black: TerraSAR-X SM).

The datasets take into consideration optical as well as SAR data in different spatial resolutions using the satellite imagery of Landsat Multi-spectral Scanner (MSS, 79m, March 1975), Landsat Thematic Mapper (TM, 28.5m, September 1987), Landsat Enhanced Thematic Mapper (ETM, 28.5m, July 2000), and TerraSAR-X StripMap mode (SM, 1.25m, March 2008) (see Figure 2).

The Landsat sensors were mapping the earth surface by 185x185km large tiles using a coarse respectively medium spatial resolution of 28.5m and 79m. Consequently, even a huge agglomeration like the wide extending megacity Istanbul could be detected by a single acquisition. TerraSAR-X, however, is able to scan the earth surface in different modes and incidence angles at a spatial resolution of 1.25m. In this study, the StripMap mode (SM) was used with a swath width of 32km including an incidence angle of some 40 degrees. By combining three neighbouring acquisition stripes, TerraSAR-X SM data have almost the same spatial extent as the former Landsat data and can be compared easily (see Figure 1).

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Satellite / Sensor / Mode	Acquisition Date	Spatial Resolution in Meters	Classification Accuracy in %
Landsat MSS	March 1975	79m	93.9%
Landsat TM	September 1987	28.5m	92.4%
Landsat ETM	July 2000	28.5m	90.8%
TerraSAR-X SM	March 2008	1.25m	92.8%

Figure 2. Overview of the used remote sensing datasets in Istanbul.

In Figure 3 parts of Istanbul's CBD near the Grand Bazaar are shown in an overview of the remote sensing data sets used in the presented study. Specific urban details like single houses block structures, and the street network can be detected easily in Ikonos reference data (top). But there is no way to distinguish urban structures in the Landsat ETM data on building / block level (middle); only coarser structures like built-up areas, parts of the road network, vegetation or open spaces can be identified. In high resolution TerraSAR-X SM data (below), however, urban structures are visually detectable. Nevertheless their classification remains difficult since the display of structures is the result of typical SAR effects like double bounce, shadowing or corner reflectors. According to [29, 30] SAR imagery cannot be analysed by typical radar interpretation keys because of these effects.

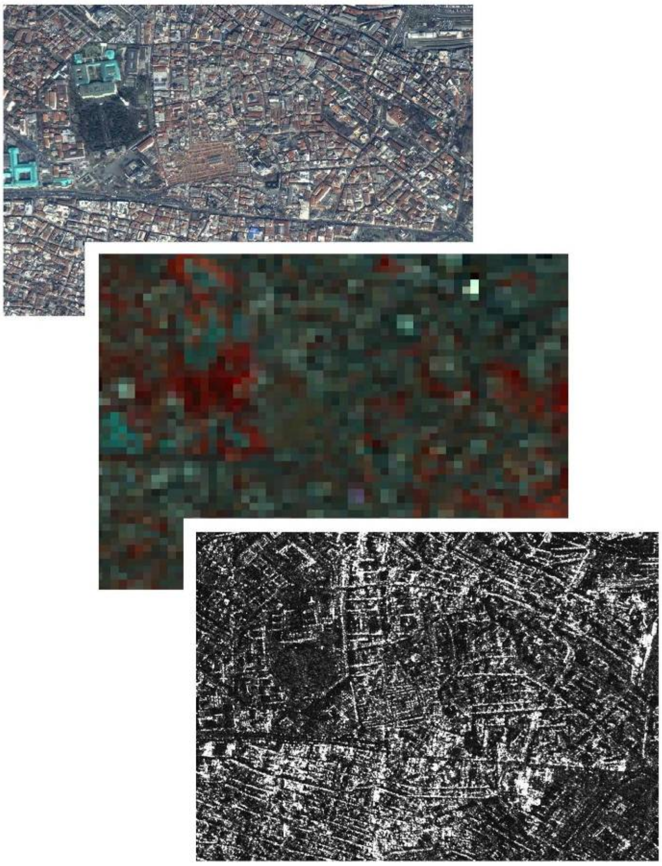

Figure 3. Comparison of spatial resolutions: Ikonos (1m, top), Landsat ETM (28m, middle), and TerraSAR-X SM (1.25m, below) mapping downtown Istanbul (Istanbul University and the Grand Bazaar).

Although different remote sensing technologies and spatial resolutions varying from 1.25 meters to 79 meters were used in the study, the output results demonstrate the potential of synergistic usage of optical and SAR data in various geometric resolutions. As the data is not used in a single classification project but a single dataset for a single time step, several constraints like varying object appearance resulting from spatial resolution, shadow effects, and acquisition geometry could be circumvented and solved by a classification of each time step per se.

IV. METHODOLOGY

Both optical and SAR data require several steps of pre-processing. The optical Landsat data have been prepared by an atmospheric correction reducing atmospheric perturbations like dust, smog, and sparse clouds. Thus, the software ATCOR 6.3 is used [31]. The quality of SAR data, however, usually suffers from speckle noise. Hence, the TerraSAR-X SM data is prepared by the so-called SelectiveMean Filter [32]. The tool is designed as an adaptive moving window filter and can be installed as an extension in the ENVI software. The filtering is based on the local statistics of the central pixel and its surrounding pixels [33]. By this method, the filter tool is able to detect highly and sparsely structured areas in the imagery and to reduce the speckle noise in less structured areas. By indication of individual lower and upper critical thresholds, best filter options can be instructed for each dataset. As already described in Chapter 3, urban areas are characterized by high backscattering resulting from double bounce and corner reflectors. According to their high scatter response, these reflectors can be easily detected during the classification process (see Figure 3 (below)). During the filtering, speckle noise in homogeneous non-built-up areas is reduced. Instead, bright and highly structured parts remain unfiltered as sure indicators for urban areas. Additionally, the speckle divergence is calculated during the filtering process and saved in a separate file. Thus, it can be used as a second information layer during the classification.

For analysing the urban footprint of the different time steps, an object-oriented classification technique is implemented using Definiens Developer software. For the image segmentation procedure a bottom-up approach is used. By generating smallest objects first at the basis level and merging them to larger objects during following segmentation cycles different classification steps can be carried out on various object levels. Complementarily to segmentation, the classification procedure is following the top-down approach [19]. At the beginning, large and homogeneous areas like water bodies (dark appearance in SAR data) or open space (intensely filtered) are classified on a higher object level and the results are extracted to a lower segmentation level. Complex and heterogeneous surfaces like urban areas are classified only on the basic level since spectral values vary because of different roof types respectively roof materials, and shadow effects by neighbouring buildings.

While the optical Landsat data offers 4 respectively 7 channels, various spectral information can be taken to distinguish several land cover classes. Indices like NDVI and

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other ratios are involved to separate water bodies or vegetation areas from sealed urban space. SAR data, however, only provide a single wave length. Consequently, spectral information is rare compared to optical data and it is more difficult to extract precise information from SAR data [32]. In order to create a SAR-based settlement mask the classification of urban area starts with the identification of sure urban structures indicated by high backscattering of corner reflectors. These reflectors are used as seed points. For optical data as well, the classification of urban areas begins with the detection of sure urban seed points. Following classification steps both in optical and in SAR data are based on the principle of region growing and refer to the seeds by relation to neighbouring objects, although the spectral values (for optical data) respectively the backscatter coefficients (for SAR data) are not as ideal as for the seed points.

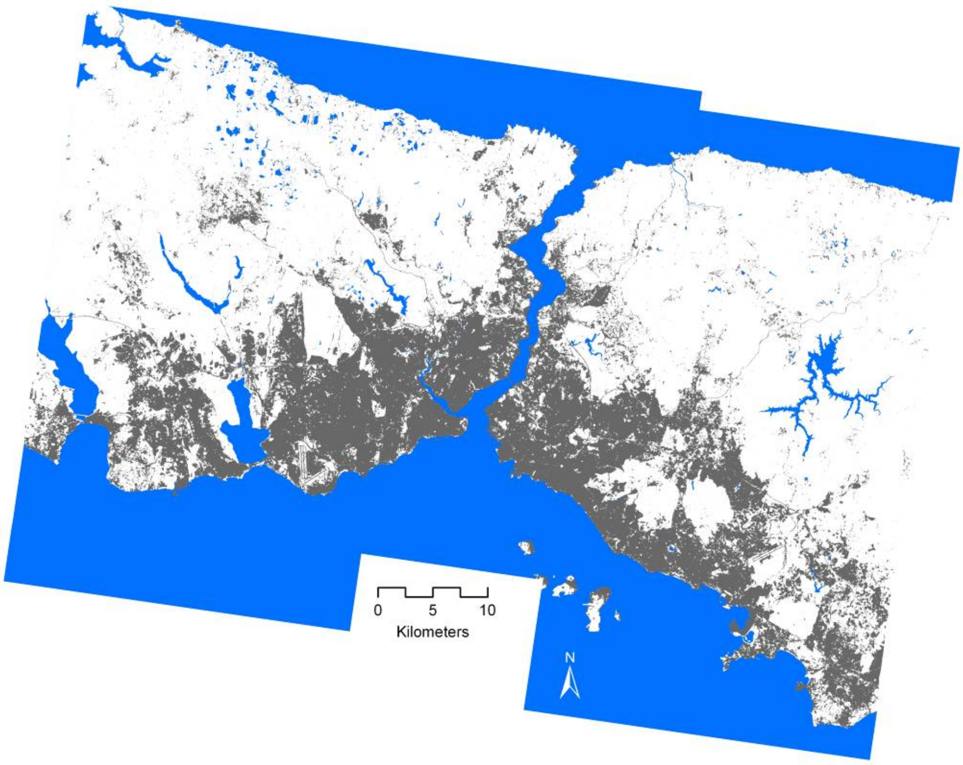
Because of coarse spatial resolution (Landsat data) respectively less spectral information (TerraSAR-X SM data) the classification is concentrating on the extraction of the main land cover types '*water*', '*vegetation*', '*open space*', and '*built-up area*'. Usually, water can be detected easily both in optical (negative NDVI) and in SAR data (low backscattering). Vegetation or open space is separable using the NDVI in optical data; in SAR imagery lower backscatter responses and medium speckle divergence indicate these classes as well.

Urban areas can be detected in SAR data by corner reflectors, high backscatter coefficients and intense speckle divergence as mentioned above. Since the analysis of optical and SAR data is based on totally different parameters, it is obvious that there are two different rule sets necessary in order to classify optical respectively SAR data in an object-oriented approach.

The generation of the land cover classification and, in particular, the settlement mask of each time step is the most important output and basis for further processing. In Figure 4 Istanbul's current urban footprint in 2008 is presented based on TerraSAR-X SM data.

Additionally, an accuracy assessment is undertaken. Therefore, each classification result is controlled by an array of random points and visually checked by using Ikonos reference data mapping parts of the CBD next to the Bosporus and the Golden Horn in 2005. Despite of different capabilities of the input data, the particular results of the urban footprints show accuracies from 90 up to 94 per cent (see Figure 2). Thus, the multi-sensoral approach enables to assess the correct dimension of spatiotemporal developments at the megacity Istanbul.

Figure 4. Urban footprint of the megacity Istanbul in March 2008 using high resolution TerraSAR-X SM data.



Ongoing, pixelwise change detection of the settlement masks of the particular time steps is performed. By calculating statistics like built-up densities and growth rates by grids based on a 250x250m wide raster urbanization is analysed quantitatively as well (see Figure 7). In spite of diverse datasets using active and passive remote sensing systems with varying spatial resolutions, urban changes at the medium and large scale can be detected in Istanbul's megacity development (see Figure 5).

V. CHANGE DETECTION AND RESULTS

The superior aim of the presented study is to analyse the urbanization process in Istanbul. The question arises if robust driving factors influence present urbanization and urban sprawl or if new urbanization trends indicate a new level of megacity development at the Bosporus. According to Figure 6, Istanbul's urban area extended continuously from 241km² in 1975 to 688km² in 2008. Nevertheless, a turnaround and slower progress in areal growth can be monitored since the millennium. In the following chapter the megacity development since the 1970ies shall be taken into consideration and driving factors for latest urban developments shall be discussed in detail.

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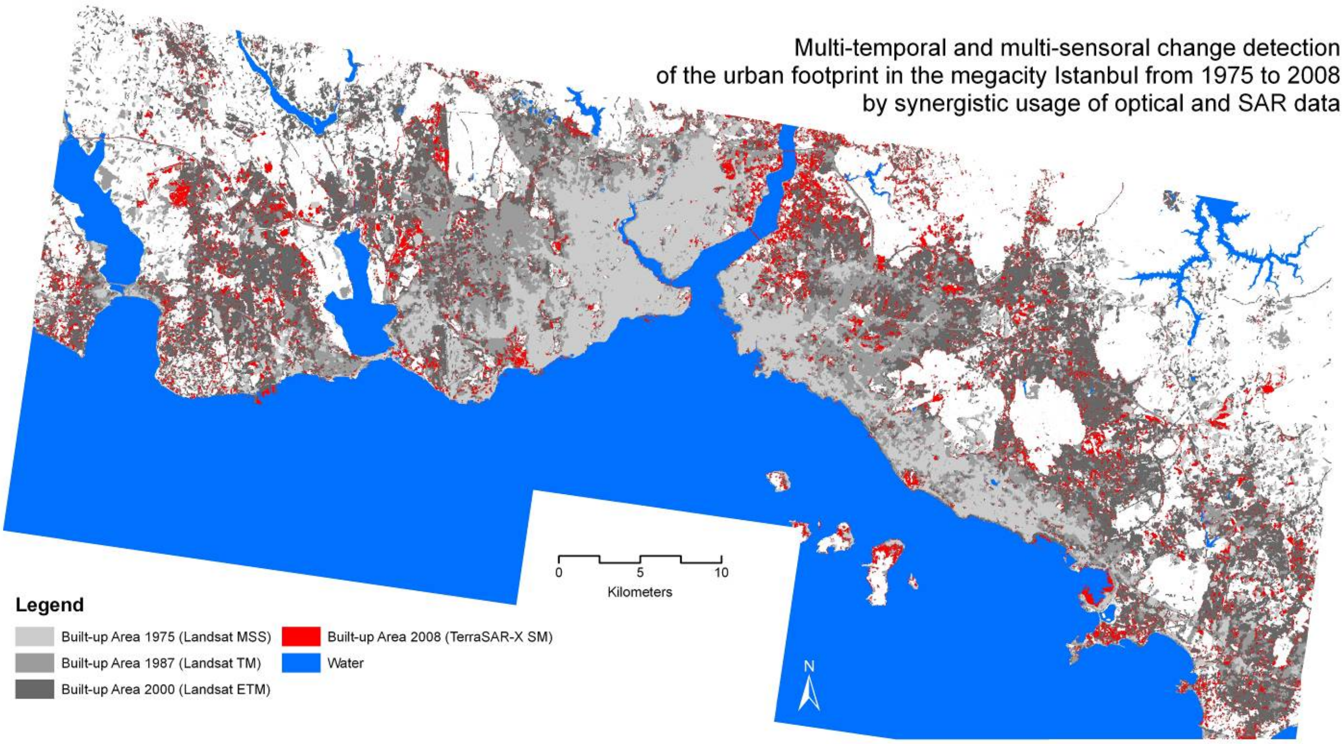


Figure 5. Multitemporal and multisensoral change detection of the urban footprint in the megacity Istanbul from 1975 to 2008 by synergistic usage of optical and SAR data.

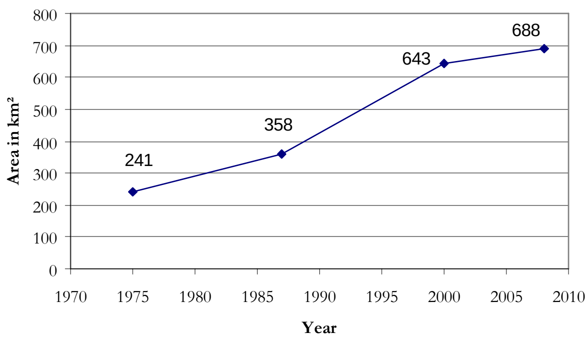
The analysis of the Landsat data indicates that Istanbul has undergone an enormous urbanization process since 1975 [3, 9, 19, 24, 34]. Spacious illegal and informal Gecekondu settlements spreading during the 1970ies to 1990ies have been detected throughout the whole megacity (see Figure 5).

Especially in the 1970ies, the focus of urbanization is located at the European side of Istanbul. Ongoing, the growth rates indicate a concentric structure of urbanization for the interval from 1975 to 1987 (see Figure 7a). Henceforth, the focus of urbanization is no longer at the European side but detectable at the Anatolian side as well and Istanbul's urban complex footprint is developing in the form of a band parallel to the seaside. Until 2000, the focus of urbanization is relocated more and more from the coastal band to the interior outskirts of the megacity.

From 1987 to 2000, the concentric growth is still detectable but it is located in greater distance to the city centre (see Figure 7b). In 2008, the urban sprawl shows a decline of spatial urbanization processes displayed in the latest TerraSAR-X SM results. After consistent urban areal growth for several decades, Figures 6 and 7c show clearly that a new development is taking place. Thus, Istanbul is facing changing urbanization factors and new forms of urbanity since the millennium.

The classification results of the SAR data in 2008 display that Istanbul is no longer influenced by spacious and unplanned urban sprawl (see Figures 5, 6 and 7c). After decades of informal Gecekondu housing, we observe different new housing trends. The framework influencing latest urbanity developments in Istanbul can be summarized as follows:

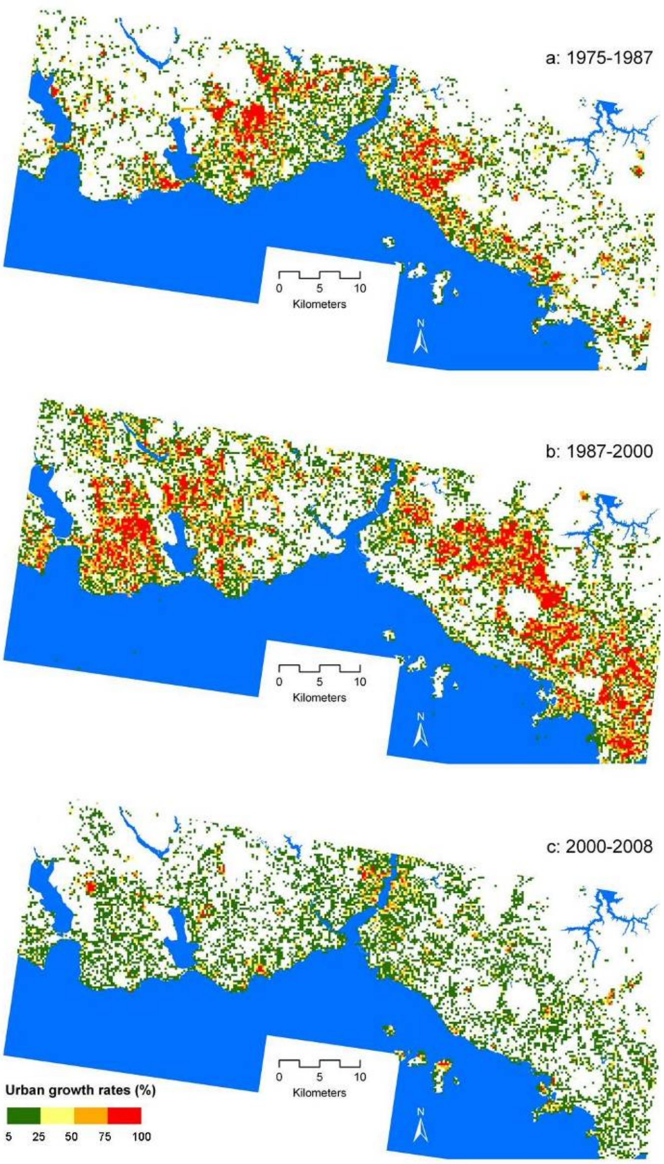
Figure 6. Areal growth (in km²) in Istanbul since 1975.



Spacious and circular areal growth caused by illegal Gecekondu housing is no longer detectable. The demand of new housing is taking place qualitatively and quantitatively at a new and small-scale level.

Instead of spacious urban sprawl in the periphery current settlement activities mainly take place in the interior parts of Istanbul's urban area. We observe a beginning of urban re-densification. Growing demand for further living space is resulting in modernization of former 'Gecekondu' settlements by densification and rising floor numbers [22].

Figure 7. Changing urbanization and growth rates in the megacity Istanbul from 1975 to 2008.



As already mentioned before, new settlement activities are detected on a smaller scale than in the decades before. Most of the new urban space is produced at favoured locations like the hills in Istanbul's hinterland or along the Bosporus seaside. Related to urban and social studies [20, 34, 35, 36] we found exactly these settlements described as areas for exclusive and luxurious living space for favoured parts of society. This development can be regarded as an indicator for a new step of megacity development: Istanbul is facing a totally new urban phenomenon typically both for global cities and megacities: very well planned and luxurious estates are rising on a much smaller spatial scale all over the urban area. These so-called gated communities can be seen as 'the new walls of the city' especially in districts favoured by topography or landscape surrounded by recreational areas or the Bosporus waterfront. Gated communities can be identified as the latest form of modern urbanity in cities causing social tensions like gentrification, segregation, exclusion, and class division. After decades of laminar spreading and massive suburbanization, Istanbul has reached a new era of urbanity and urban development. The current development is pointed up by the fact that in 1999, Istanbul has been proclaimed as a so-called Gamma World City and new sustainable urban transformation projects were carried out [4, 37].

VI. CONCLUSION

After the precise discussion of the change detection results and their comparison and conformity to interdisciplinary urban studies, our study shows that monitoring megacities can be consistently continued on city level using TerraSAR-X data. The multi-sensoral / -temporal approach enables to assess the correct dimensions of urban growth, its directions and the large-area patterns. Although various remotely sensed optical and SAR datasets have been used it is possible to analyse a changing urbanization pattern and urbanity in Istanbul since 1975. The results being completely deduced by object-oriented classified satellite imagery are harmonising with social urban studies and indicate great potentials of multi-disciplinary approaches for urban studies in megacities.

In the presented study, we were working with multispectral data (but medium respectively coarse geometric resolution) and high resolution SAR data (but low spectral information). Nevertheless we were able to classify meaningful settlement masks in order to detect and to analyse medium- and large-scale urban developments in the megacity Istanbul from 1975 to 2008. For ongoing research, further focusing on synergistic potentials both in optical and SAR remote sensing respectively in urban remote sensing and neighbouring disciplines like urban planning und megacity management seems promising. Urban systems are highly complex and heterogeneous; therefore multi-dimensional and multi-disciplinary research approaches might be regarded as adequate instruments and tools for urban analysis, monitoring, and management.

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